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ON METAMORPHIC ROCKS IN EASTERN TYRONE AND SOUTHERN DONEGAL.

BY GRENVILLE A. J. COLE, F.G.S.,
Professor of Geology and Mineralogy in the Royal College of Science for Ireland.

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XI.

ON METAMORPHIC ROCKS IN EASTERN TYRONE AND SOUTHERN DONEGAL.

By GRENVILLE A. J. COLE, F.G.S., Professor of Geology and Mineralogy in the Royal College of Science for Ireland.

(Plates XXVI., XXVII.)

[Read February 12th, 1900.]

I.—Introduction.

In 1896, when studying the geological features of Slieve Gallion,* I was led to visit the complex region west of Cookstown, in the county of Tyrone, the eastern flank of which does much to elucidate the relations of the rocks upon Slieve Gallion. Around Oritor, the gabbros and diorites, penetrated by granite, eurite, and soda-orthoclase-rock, present a fine picture of the basal intrusive masses which here and there gave rise to volcanic manifestations at the surface. The andesitic tuffs and lavas of Slieve Gallion, the agglomerates of Beaghbeg and Broughderg, and the highly silicated tuffs of Creggan, clearly represent an ancient series into which the typical granite of the district has intruded. In the centre, however, of the area in which these rocks are exposed lies the well known gneissic mass stretching from near Pomeroy to Lough Fea; and various problems are presented by its proximity to the granite of Slieve Gallion. In the past four years I have made various traverses of the district, and have studied particularly the granites of the southern zone, stretching from Craigballyharky to the Camowen River near Beragh; their features have been at the same time compared with those of the central gneiss. The gneissic exposure to the north of this zone being limited, I felt that it would be well to extend the investigation to the rocks of a wider area. The Royal Irish

* "On the Geology of Slieve Gallion, in the county of Londonderry." Scientific Transactions Royal Dublin Society, vol. vi. (1897), pp. 235 and 243.

Academy, in 1899, encouraged me by a grant for the examination of the metamorphic rocks of southern Donegal; and the results obtained from both areas are set down in the present paper.

The problem presented both at Pomeroy in Tyrone and Pettigo in Donegal may be stated as a series of questions:—

(i.) Is the intrusive granite distinct from the gneiss, or is the former merely an offshoot from the latter?

(ii.) Is the gneiss itself an igneous rock, and if so, has it assumed its local richness in ferromagnesian minerals by absorption of basic and other rocks adjoining it?

(iii.) If the gneiss is distinct from and older than the granite, what claim has it to be regarded as Archæan and fundamental?

It may be well to sum up the views hitherto expressed as to the age of the rocks in question. Even the clearly intrusive granites were at first supposed to result from the metamorphism and local fusion of sediments *in situ**; and both the basic and the highly silicated igneous series of Slieve Gallion and eastern Tyrone were regarded as having been produced, by progressive alteration, from masses of one and the same age. Portlock† showed that granite pebbles occurred in conglomerates of Llandovery age in the county of Fermanagh; and he evidently felt that the granite of Slieve Gallion was, at any rate, pre-Silurian. The memoirs of the Geological Survey of Ireland record that *débris* from this granite are found in the Lower Carboniferous sandstones on its flanks; but the granite was held, on the other hand, to be intrusive in Lower Devonian rocks at Carrickmore. If verified, these observations would have assigned to it, as I stated in 1897, a Middle Devonian age. An examination of the critical junction‡ near Aghnagreggan Bridge in 1898 showed, however, that the Lower Devonian sandstone contains numerous blocks derived from the adjacent granite, which is clearly of the Slieve Gallion type; and hence the granite is pre-Devonian, and its maximum age is not yet ascertained.

* Portlock, "Report on Geology of Londonderry, &c." (1843), p. 556.

† *Ibid.*, pp. 232 and 557.

‡ G. A. J. Cole, "On the age of certain granites in Tyrone and Londonderry." Quart. Journ. Geol. Soc., vol. lv. (1899), p. 273.

Should the basic series penetrated by it prove to be of Arenig age, as Mr. G. H. Kinahan* and Sir A. Geikie† have suggested, the granite throughout the Tyrone and Londonderry area may be connected, with great probability, with the "Caledonian" earth-movements, which occurred at the close of Silurian times.‡

As I have elsewhere stated, Mr. Joseph Nolan,§ who so carefully surveyed the district north of Pomeroy, suggested that the intrusive granite may have been derived from the depression and remelting of the ancient gneissic core; though later, in his official memoir, he classed both rocks together as Precambrian. Whatever view we may adopt, the granite is clearly the later member of the highly crystalline group in east Tyrone.

The gneiss north of Pomeroy has been pretty generally treated as Archæan, from the time that Dr. Hicks‖ included it, on evidence supplied by Mr. G. H. Kinahan, among his Precambrian areas in the British Isles. The statement has, indeed, stood the test of time better than many made in the early days of Precambrian controversy. Professor Hull¶ discussed the question fairly and fully in 1882, though it is difficult to understand his association of the gneiss, the basic igneous series, and the later granite, as necessarily forming one connected series. Mr. Nolan,** in the Survey Memoir of 1884, gave a good sketch of the central "gneiss and schist," but also hesitated, as we have seen, to divide this mass from the granite of

* "Economic Geology of Ireland," Journ. R. Geol. Soc. Ireland, vol. viii., p. 160; also "Archæan Rocks," Geol. Mag., 1887, p. 507.

† "Ancient Volcanoes of Great Britain," vol. i. (1897), p. 239.

‡ Bertrand, "Distribution géographique des Roches Éruptives en Europe." Bull. Soc. Géol. de France, 3me. série, t. xvi., p. 576.

§ "On the Metamorphic and Intrusive Rocks of Tyrone." Geol. Mag., 1879, p. 159; and Memoir to Sheet 26, Geol. Surv. Ireland (1884), pp. 10 and 15.

‖ "On some recent researches among pre-Cambrian rocks in the British Isles." Proc. Geol. Assoc., vol. vii. (1881), p. 86. Also G. H. Kinahan, "Supposed U. Cambrian Rocks in Tyrone and Mayo." Proc. R. I. A., ser. 2, vol. iii., p. 344.

¶ "Laurentian Rocks of Donegal and of other parts of Ireland." Sci. Trans. R. Dublin Soc., vol. i. (1882), p. 254.

** Memoir to sheet 26, p. 15.

the Slieve Gallion type. Sir A. Geikie,* in 1891, spoke of the district as including "an undoubted core of Archæan gneiss, resembling in all essential characters the Lewisian rocks of the north-west of Scotland." As we shall see, nothing has yet transpired to shake our faith in this conclusion.†

Few distinct references were made, prior to 1891, to the larger area in the south of the county of Donegal. Discoveries in Scotland led Jukes‡ to suggest, as far back as 1862, that Precambrian rocks occurred among the northern Irish gneisses. Mr. G. H. Kinahan§ held, in 1878, that these rocks might be "Cambrian, or even Laurentian"; but Professor Hull‖ omitted the southern exposures from his account of the "Laurentian Rocks of Donegal." Mr. Kinahan,¶ five years later, distinctly correlated the rocks of the Slieve Gallion (Pomeroy) area with those of Pettigo, and stated that they belonged "either to the Arenig or the Cambrian." In 1891, however, both Professor Hull** and Sir A. Geikie agreed that the gneisses from Ballyshannon to Pettigo "are clearly to be paralleled with the Lewisian gneiss of Scotland as parts of an ancient Archæan core."††

II.—Results of the Intrusion of the Slieve Gallion Granite into the Basic Igneous Series of Tyrone.

I have elsewhere described‡‡ the general characters of the granite of Slieve Gallion. It is sometimes poor in ferromagnesian constituents, and becomes, in its fine-grained offshoots, almost aplitic. Green mica is, however, commonly present; but the hornblendic varieties owe their hornblende to the absorption of material from adjacent diorites. It is even possible that the dark mica itself is a product of absorption, seeing that it has so

* Anniversary Address. Quart. Journ. Geol. Soc. Lond., vol. xlvii., p. 77.

† Compare G. Cole, "The Structure of Ireland." Knowledge, vol. xxi. (1898), p. 75.

‡ "Students' Manual of Geology," 2nd ed., p. 433.

§ "Manual of the Geology of Ireland," p. 191.

‖ Sci. Trans. R. Dub. Soc., vol. i. (1882), p. 243.

¶ "Archæan Rocks." Geol. Mag., 1887, p. 507.

** "Physical Geography and Geology of Ireland," 2nd ed., p. 8.

†† Mem to sheets 31 and 32, Geol. Surv. Ireland, p. 13.

‡‡ Sci. Trans. R. Dublin Soc., vol, vi., p. 229.

often developed as the last constituent during the consolidation of the mass. The crystals of the solidifying granitic magma may have retained molten foreign material between them; this at last was able to crystallise, and produced the interstitial biotite. While this appears to be the true explanation in local instances, it would none the less be rash to apply it to the whole of the biotite-granites of Tyrone, from Slieve Gallion to the Beragh area.

These granites, however, are obviously repetitions of the Slieve Gallion type, and are usually biotite-granites of medium grain. The number of points where conspicuous veins come up through the diorites and dolerites on either side of the gneissic axis shows that the granite is never far below us, and that its extent in east Tyrone is really very considerable. Many of these occurrences cannot be indicated upon the Survey map on the scale of one inch to a mile; but the area north of Oritor is seamed with granite and eurite (microgranite), while veins of these rocks occur in the gabbro of Corkhill Bridge, north of the Kildress Inn; in Beaghbeg *; at Black Rock, south of Broughderg Bridge; and even in the rhyolitic tuffs of Creggan, where considerable intermingling with the volcanic series has gone on. The recent excavation, showing granite of the Slieve Gallion type, in Mullaghslin Glebe, three miles west of Carrickmore, indicates that a good many areas of the granite may still lie hidden under bogland.

One character of these pink granites is the frequent occurrence in them of calcite. The rock from Mullaghslin Glebe effervesces with cold acid, along the cracks of the quartz, and in patches amid the felspar and the biotite. In Carndaisy Glen, Slieve Gallion, calcite has here and there replaced the felspar in an aplitic type of the rock, and surrounds the quartz, which remains unaltered. But at Limehill Upper, north of Pomeroy, a more remarkable replacement has occurred. The granite here contains pink-red felspar, some part of which is soda-orthoclase, while a larger part is repeatedly twinned oligoclase. Dull green pinite, rich in potash, probably represents orthoclase that has been lost by alteration. Altered greenish biotite, and some muscovite, occur. The quartz is present, as usual, in interstitial granules moulded against the felspar crystals; but, in

* Sci. Trans. R. Dublin Soc., vol. vi. (1897), pl. xiv., fig. 6.

certain areas, its place is almost entirely occupied by calcite. A little quartz remains in these calcitic regions, appearing, under the microscrope, as pegmatitic detached areas amid the clustered calcite granules. At other points, the quartz has an envelope of calcite between it and the adjacent felspar, while its cracks are also filled by crystalline bands of calcite. When a specimen of the rock is immersed in hydrochloric acid, the hollows left by the removal of the calcite are seen to contain projecting tongues or loosened granules of clear quartz. The fact that the quartz associated with the calcite is far less in bulk than that which occurs in corresponding but uncalcified portions of the mass is now brought out even more distinctly than in the microscopic section. Minute patches of calcite occur, with ferriferous epidote, within the felspars; but the great mass is localised in the spots where quartz would occur in the normal type of the same rock. The felspars, moreover, are not invaded by the calcite along their boundaries; in some cases the junction with the calcite even exhibits remarkably clear material, as if a secondary zone had been added to the felspar during the processes of recrystallisation in the mass. The quartz has, however, been vigorously attacked, and calcite has been deposited in its place.

The pegmatitic appearance of the residual quartz among the grains of calcite reminds one of the remarkable veins of quartz-barytes-rock described by Mr. T. H. Holland.* These penetrate pyroxenic gneiss in the Madras Presidency, and occur in the manner of ordinary igneous veins. In the rock of Limehill, however, there can be little doubt as to the secondary character of the calcite, and as to the deficiency of quartz where it occurs. The fine-grained rock of Carndaisy Glen must, none the less, be borne in mind; and it is possible that in other parts of the Limehill mass calcite may be found replacing felspar.

This calcite-granite of Limehill has been discussed by earlier writers, and has actually been quarried as a source of lime. Portlock† referred the calcium carbonate, with some hesitation, to a pre-existing limestone, in which the granitic material had developed by metamorphic action; while

* Records Geol. Survey of India, vol. xxx. (1897), p. 236.

† "Geol. Rep. on Londonderry, &c.," p. 555.

Mr. Nolan,* with more probability, ascribed it to "infiltration, Carboniferous rocks having probably extended over all this part of the country."

The modifications of the Tyrone granite, however, to which I would call particular attention, are those brought about at its contact with the basic and the schistose rocks. There is no evidence that the Limehill rock has resulted from the "endomorphic" effect of limestone swallowed up in granite. In such cases, pyroxenic and garnetiferous rocks seem to arise, and the calcium carbonate is destroyed.† Even in the milder cases of inclusions in lavas and tuffs, where crystalline calcite remains in the metamorphosed rock, silicates, such as wollastonite and other pyroxenes, garnet, and idocrase, commonly arise by interaction.‡

Where, however, the Tyrone granite traverses the basic igneous series, considerable "endomorphic" change is set up in it near the junction. I have already described§ the production of hornblende-granites and quartz-diorites in the region lying to the east; and similar hornblendic modifications, styled "Syenite" by Portlock and the later surveyors, result from absorption of the basic series by the granite round about the gneissic axis of Tyrone. The "syenitic" features in the granite of the rocky hills of Craigbardahessiagh, Garagrim, and Craigballyharky, north-east of Pomeroy, are by no means uniformly diffused. The main mass is a biotite-granite, as has been pointed out by Mr. Kinahan,‖ who compares it to that of Omey, in the county of Galway. I see no reason, however, for regarding this granite as distinct from that which elsewhere forms veins and protrusions among the diorites and diabases; it appears, in its normal state, to be of the Slieve Gallion type. But it becomes enriched with hornblende at its numerous junctions with the basic series, as on the south-west and east sides of the summit of Garagrim, on the west side of Craigballyharky, and about the steep cliff

* Mem. sheet 34, p. 15.

† See Michel Lévy, "Granite de Flamanville," Bull. des Services de la carte géol. de la France, tome v. (1893), p. 337.

‡ See A. Lacroix, "Les Enclaves des roches volcaniques" (1893), pp. 252–260.

§ Sci. Trans. R.D.S., vol. vi., pp. 226 and 230.

‖ *Op. cit.*, Proc. R.I.A., ser. 2, vol. iii., pp. 344 and 345.

which bounds Craigbardahessiagh on the north. The microscope shows abundant idiomorphic hornblende, twinned at times on the orthopinacoid, as a prominent constituent of the junction-granite of Garagrim; sphene is also well developed*; but otherwise, with its green biotite and its curious globose masses of quartz, it is the same rock as that which weathers out along the summit of the hill.† In the field, the granite magma is seen to have taken off flakes from the compact aphanites, the absorbed material of which has recrystallised as hornblende.‡

In the case of inclusion in lavas, as Lacroix§ again and again points out, pyroxene recrystallises from the products of melting of pyroxenic and amphibolic rocks; but it is clear that hornblende is the ordinary product when the interaction occurs under the attack of a deep-seated and highly siliceous magma. The whole compound mass becomes one of intermediate composition, and a granite and a gabbro interfused will thus form a representative quartz-diorite.

M. Michel Lévy,‖ to whom we owe so much of our knowledge of the contact-effects of granite, has pointed out how amphibole-granites give evidence of rapid variations in the composition of their magmas, during the crystallisation of their constituents. He also shows,¶ by direct evidence in the field, how the absorption of basic schists by a normal granite gives rise

* Compare M. Lévy, "Sur l'origine des terrains cristallins primitifs." Bull. Soc. Géol. de France, 3me. série, t. xvi., p. 112.

† Mr. Nolan describes this area with his customary accuracy of observation (Mem. sheet 34, p. 10), and his view of the gradation of the one type of rock into the other supports the hypothesis of what is now known as "differentiation" in a cooling igneous mass. The same questions will have to be fought out in the field in all those cases where either differentiation or mutual intrusion may have occurred. I have no doubt as to the correctness of the intrusive view throughout Tyrone.

‡ The intrusive character of this granite in the hornblendic rocks was well noted by Portlock. ("Rep. Londonderry, &c.," p. 522.)

§ "Les Enclaves des roches volcaniques." Compare also the experiments of Doelter and Hussak, "Ueber die Einwirkung geschmolzener Magmen auf verschiedenen Mineralien." Neues Jahrbuch für Min., &c., 1884, Bd. I., p. 24.

‖ "Sur l'évolution des magmas de certains granites à amphibole." Comptes rendus, tome cxxi. (1895), p. 228.

¶ "Granite de Flamanville," *loc. cit.*, p. 340.

to granite rich in hornblende. M. Charles Barrois* has made similar observations on the quartz-diorites produced by the passage of the granite of Laumur in Brittany through uralitic diabases, and on the St. Brieuc granite, near its contact with pyroxenites and amphibolites. Sederholm,† shows how in Finland a basic type of granite, rich in hornblende, arises from the absorption of blocks of diorite. The "Caledonian" granite of Crossdoney, in the county of Cavan, has converted the sedimentary patches included in it "into hornblendic and micaceous *hornfels*."‡ I have given other references in my paper on Slieve Gallion, notably to the work of Prof. Sollas, and an excellent and well studied example of the kind has recently been provided by Mr. J. Parkinson§ from Jersey.

These cases are more extreme than those in which the hornblende is merely picked off from a pre-existing amphibolic rock. The invading magma has mingled with actually fused foreign material, and the hornblende has crystallised out, like the quartz and orthoclase, from the compound molten mass. At Black Rock, however, a boss in the moorland of Tyrone, northwest of Evishbrack, an invading eurite has become stuck full of hornblende, by simple derivation of this mineral from a uralitic diabase. The derived crystals are rounded, and often retain traces, clinging to them, of the more minutely developed constituents of the diabase.

This example was studied on account of its possible bearing on the origin of the central gneiss. Though the junction is ragged, and though flakes of the schistose diabase are picked off, by the eurite, retaining indications of their previous parallelism, there is nothing to suggest that an extension of such action could have produced the superb biotite-gneisses of Evishbrack and of the central core in general. At Cregganconroe, however, $2\frac{1}{2}$ miles north-west of Pomeroy, the Slieve Gallion granite penetrates

* Communication made after excursion to Aydat, Bull. Soc. Géol. de France, 3me. sér., tome xviii. (1890), p. 919.

† "Über eine archäische sedimentformation, &c." Bull. Comm. géol. Finlande, No. 6 (dated Feb. 1899 on cover, 1897 within), p. 132.

‡ M'Henry and Watts, "Guide to rocks and fossils, Geol. Surv. Ireland" (1895), p. 76.

§ "On an intrusion of Granite into Diabase at Sorel Point (Northern Jersey)." Quart. Journ. Geol. Soc., vol. lv. (1899), p. 430.

hornblende-aphanites and a coarsely ophitic diorite. In this last rock, the irregularly bounded ophitic crystals of hornblende measure at times 35 millimetres across. On the south side of the rocky summits, the basic series meets the main mass of the granite, which stretches from Lime Hill westward. The aphanite is carried away in strips and layers by the granite, which still flowed as it attacked the basic rocks. Some of the derived flakes retain their dull lime-felspars and green granular hornblendes in their relative positions; in the smaller layers the felspar has disappeared, and the hornblende has become streaked out into minutely granular green films. The flow of the granite has given an ovoid contour to its own larger orthoclase crystals, and the quartz and smaller felspar have settled down in a granular mosaic between them. This mosaic, with its obvious fluidal arrangement, the undulating films of basic material, and the characteristic felspar "eyes," give the compound rock the aspect of a gneiss produced by pressure on material already solid (Pl. xxvi., fig. 1). The question so often raised in the case of large bodies of gneiss naturally arises again here. The absence of "strain-shadows" in the larger crystals when seen in microscopic section, the undeformed intrusive veins of granite that are visible at the junction in the field, and, indeed, all the evidence obtainable on the ground itself, decide that this miniature gneiss is a composite rock produced by igneous flow. In such cases, however, we may remember that the flow always goes on under the pressure of superincumbent masses, and that a lenticular form is given, by external conditions, to any crystals that develope boldly, and to any included material that is dragged along in the hot magma.* Hence the distinction between pressure-flow, with consequent mylonitic structure, and igneous flow, with the production of bands of minutely granular constituents, must often be made in the field itself, and can only rarely be established in the case of isolated specimens.

The example at Cregganconroe is on quite a small scale. Here, again, the flow-gneiss produced by interaction of the granite and the basic series is quite unlike any of the varied masses that go to form the central gneissic core. It obviously resembles, however, the banded rock described by

[1] See M'Mahon, "Structural characteristics of the granite of the north-west Himalayas." Proc. Geol. Assoc., vol. xiv. (1896), p. 287.

Mr. Jaquet* as arising at the junction of eurite and amphibolite in New South Wales, in which rounded hornblende grains "in many instances can be seen flowing round the authigenic felspars."

I am far, however, from suggesting that the gneisses in the axis of east Tyrone owe their more prominent characters to dynamo-metamorphic action rather than to igneous flow. On the contrary, I believe that parallel intrusions of granite, in ancient times, have done much in this case to modify an original schistose series, and to impart to it a gneissic aspect. But there is no evidence that the gneiss itself has arisen from plutonic intermingling of the Slieve Gallion granite with the basic series which it traverses on the margins of the gneiss.

III.—Relation of the Slieve Gallion Granite to the Metamorphic Series.

The existence of a thoroughly metamorphosed series in east Tyrone, prior to the intrusion of the granite of the Slieve Gallion type, is fortunately demonstrable in the field. At the extreme south-west end of the gneissic exposure, at Sultanbane, $1\frac{1}{4}$ miles north-west of Cregganconroe, the granite comes up in pinkish veins into the gneiss, which becomes intimately incorporated with it. On the east side of the main road, the granite is highly charged with nests and strings of green biotite, and seems thus to graduate into a true dark biotite-schist. On the west side, it is intermingled, on a microscopic scale, with fine-grained biotite-gneiss of a type that is fairly common in the central axis. The pink granite veins here and there are seen to cut across the foliation-layers of the gneiss. The biotite in these granite veins occurs in much larger crystals, and happens here to be greatly altered and associated with muscovite; otherwise there would be much difficulty, in a microscopic section, in delimiting the granite from the gneiss. The granite itself has suffered from earth-stresses during or since its intrusion, as is seen from the behaviour of its crystals between crossed nicols. The obscurity shrouding the exact nature

* "The intrusive and metamorphic rocks of Berthong, Co. Bland, N. S. Wales." Records Geol. Surv. N. S. Wales, vol. v. (1896), p. 20.

of the various rocks of Sultanbane has already been discussed before the Dublin Microscopical Club, in 1897.*

Decisive evidence as to the relations of the granite and the metamorphic axis is found, however, on the ascent of Fir Mountain from Cookstown. Portlock† records veins of "rose-coloured felspathic and slightly hornblendic granite," as traversing the gneisses in the bed of the Clagan Water near Lissan, a spot where I have failed to find good exposures at the present time. The same author‡ states that "the schistose rocks of Fir Mountain dip to the north-east and east; they consist of dark-coloured micaceous gneiss and schist, the colour being derived from the prevalence of black mica, and the occasional presence of hornblende; layers or laminæ of reddish felspathic and syenitic granite are of frequent occurrence." This represents, I believe, a very accurate reading of the mass. Mr. Nolan§ also indicates the mingling of the various types of rocks on Fir Mountain, which he describes as consisting of "micaceous schists and gneiss succeeded by a coarse variety with obscure foliation and containing hornblende, till north of the summit we meet with rocks that it is almost impossible to relegate with certainty to either class."

As the road through the townland of Creeve to the foot of the Wolf's Hill emerges on the open moorland, blocks are found showing angular fragments of gneiss and schist included in brown biotite-granite. At the angle of a wall, a little to the north of the road, similar rocks are seen apparently *in situ*. We see here, as clearly as in the quarries of Castlewellan in county Down, the fragmentation of a pre-existing rock by the inflow of a granite magma.

The pre-existing rock was in this case already foliated. The fragments have now no common direction of foliation; and they lie embedded in a granite that is devoid of structural planes. Some of them consist of fine-grained biotite-gneiss; other of dark biotite-schist. Under the microscope, the gneiss is seen to be of the type common in the district, rich in quartz-granules of fairly even size, fitting into one another more as a mosaic than

* Irish Naturalist, vol. vii. (1898), p. 23.

† "Geol. Rep. Londonderry, &c.," p. 535.

‡ *Ibid.*, p. 536.

§ Mem. sheet 26, p. 15.

by interlocking, and with dusky felspars that have developed slightly later than the quartz; small brown biotites and magnetite grains occur, and were the earliest constituents to crystallise. The biotite and magnetite are thus often embedded in the quartz. A little epidote has arisen, apparently in felspathic areas, but doubtless, judging from other instances, assisted by the decomposition of adjacent biotite. When a microscopic section includes both the gneiss-fragments and the surrounding granite, the boundaries of the fragments are difficult to trace, though they are clear enough in the rock itself. The granite has become highly charged with biotite, which occurs in clusters, indicating the almost complete destruction of some of the fragments of foreign rock. In places the biotite is interstitial, and the minerals of the granite have developed against a recrystallising knot of ferromagnesian material (Pl. XXVI., fig. 2). The included rock-fragments have doubtless suffered further metamorphism than was their lot before they were picked off from the old schistose core, while many must have become altogether absorbed. Additional biotite, as is usually the case, has resulted from the attack made upon them*; but the pre-existing biotite in the fragments is associated with minute densely matted prisms. These are colourless in microscopic sections, and form, by aggregation, opaque white strings in specimens of the rock. They prove to be sillimanite, and a product of the second metamorphism; moreover, MM. Lévy and Lacroix† lay special stress on the occurrence of this mineral in micaschists and gneisses metamorphosed by contact with granite ("granulite"). In our present case, the prisms seem to have developed as an alteration product of the original brown biotite, since they are so intimately associated with it, and so densely massed throughout its

* I regret that I cannot here apply the observations of Dr. Lehmann ("Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine," p. 144), who states that the granite in Saxony is associated with an excess of biotite in the adjacent metamorphic rock, because the layers already most rich in biotite provide the most easy paths by which the granite can intrude. Lehmann regards this biotite as arising from pressure-metamorphism at an earlier period. His "biotite-granulite," injected by the granite of Auerswald, presents the most interesting analogy with the rocks of Craignayarrow, in Tyrone. (See his Plate I., figs. 1 and 4).

† "Les Minéraux des Roches," p. 274.

crystals.* They are infusible before the blowpipe, and yet give a fine blue reaction with cobalt nitrate, as may easily be seen on subsequent microscopic examination.

On ascending farther towards Top Heights, at a point south-west of the farm of Craignayarrow, a rugged little exposure shows us pink granite veins invading a dark biotite-schist. The principal veins of the granite cut across the foliation-planes of the schist, but also send abundant delicate offshoots along them. The metamorphic rock near the junctions is locally converted into a felspathic and representative gneiss, such as is common above upon the ridge of Fir Mountain.

Much of the pinkish veining, then, of the more gneissose rocks of Craignayarrow, and much of the delicate interlamination of the schist with bands of quartz and felspar, are clearly traceable to the intrusion of the Slieve Gallion granite. The original rock here appears to have been a well foliated but fine-grained biotite-schist; this contains layers of dark soft matter like "pinite," which proves its minutely micaceous nature under the microscope, and gives a fine reaction for potash with the flame-test in sodium carbonate. In these "pinitic" or "sericitic" layers, well developed but small biotite occurs, and is streaked out parallel to the foliation. Rutile occurs, moreover, freely in these layers, the longer axes of its prisms lying also parallel to the foliation-planes. Quartz, with a little muscovitised felspar, forms in general about half the bulk of the rock, and is disposed in lenticular grains, or elongated groups of grains, in among the layers of the more yielding micaceous constituents. But, now and then, more pronounced granitoid bands appear in a microscopic section of these rocks; and we are forced to admit that such veins may have arisen, like their more obvious neighbours which are traceable in the field, from the saturation of the old schist by granite. Where the schist has been invaded by the undoubtedly later granite, the "sericitic" bands tend to disappear, and the granite becomes charged with biotite somewhat coarser than that in the original schist. This recrystallisation of the material that has escaped complete absorption, and the consequent richness

* Cf. M. Lévy, "Formation gneissique du Morvan," Bull. Soc. Géol. de France, 3me. série, t. vii., pp. 861 and 869; Zirkel, "Lehrbuch der Petrographie" (1893), Bd. i., p. 390.

of the granite in biotite, have already been noticed in the case of the rocks a little farther to the south.

The included fragments of metamorphic rocks proved, in the previous case, that fine-grained gneiss formed part of the older series. Hence it is probable that the gneissic rocks found west of Craignayarrow were originally coarser in structure than the adjacent biotite-schists. They tend to lose their distinct foliation, and to become more flinty, at contact with the Slieve Gallion granite.

It is impossible, however, to distinguish the broader granitoid bands in them, consisting of undeformed and interlocked grains of quartz and orthoclase, from those of intrusive origin found nearer to Craignayarrow. Biotite is streaked out in strings and layers between these granitoid bands, and everything again suggests a dual origin for the mass. An interesting parallel is provided by the well-known granite of Barnesmore in southern Donegal, which clearly traverses, at the south end of the gap, the foliation-planes of the biotite-schists; mica has been taken up, however, in abundance by the granite, and has been carried along by its flow. Hence the granite is not only completely darkened, but has produced a delicate "endomorphic" foliation of its own. I must confess that specimens collected by me in the field as "typical gneiss of the Craignayarrow area" come the more under suspicion the more I enquire into their characters.*

What, then, of the gneiss of Top Heights, and of the ridge leading up to Fir Mountain? The nature of this rock is fairly uniform, and the general dip of the foliation-planes is to the south-east. It is dark and highly micaceous, with a certain admixture of muscovite, which is unnoticed except in microscopic sections. Pinkish felspathic layers are prominent at the summit of Fir Mountain, and intrusive veins of granite occur in the rock near the road on the north-west side. It has, however, the aspect of

* It is worth noting that at the north-west end of the schistose boss near Craignayarrow a mass of hornblendic diabase (altered dolerite) appears, also traversed by the granite veins. But its relation to the schist and gneiss of the district is not seen, and it is possible that it is not actually *in situ*. Several blocks of similar rock, with granite veins in them, have been transported in glacial times to the higher slopes of Fir Mountain, and also to Glenarudda across the valley (see *op. cit.*, Sci. Trans. R. Dub. Soc., ser. ii, vol. vi, p. 227).

a rock that was gneissic before the intrusion of the Slieve Gallion granite; but at best it was dull and fine-grained, compared to the more handsome examples of gneiss on Slievemore or Evishbrack. Due west of the summit of Fir Mountain, at about the 900 feet contour-line, the foliation of the gneiss becomes contorted on a fairly bold scale.

Across the road, and half a mile to the south, the prominent mass of Friar's Rock calls our attention to the central core of the district. The evidence of Craignayarrow and Sultanbane has at any rate proved that schists and gneisses existed here before the inflow of the Slieve Gallion granite. So far, this evidence has served to emphasise the antiquity of the metamorphic axis.

IV.—The Rocks of the Central Axis between Pomeroy and Lough Fea.

The variable character of the metamorphic rocks that form the highland north and south of the Ballinderry River makes any continuous description of them only possible after a detailed mapping of the district. I propose, however, to select a few types and to suggest some general deductions.

The country occupied by the gneisses rarely rises to more than 1200 feet above the sea, but has a broad and impressive moorland character. The gigantic eskers and gravel-mounds deposited across it, sometimes enclosing little lakes, add to the desolate strangeness of the scene.* Col. Portlock and Mr. Nolan† have indicated the passage from biotite-schist to coarser granitoid rocks in various portions of the mass. I think that the obscurity in the foliation, and the difficulties of delimitation referred to by Mr. Nolan, where the metamorphic series meets the basic igneous rocks on either side, are due to the frequent irruption of the later granite along the boundary, and to its penetration of both series alike. Both the gabbros and dolerites, and the Slieve Gallion granite, seem to have met with a tough obstacle in the gneissic mass. They have come up successively on either side of it, but do not seem to have penetrated its core. The earth-movements that

* *Cf.* Portlock, "Geol. Rep. Londonderry, &c.," pp. 531 and 536.

† "Metamorphic Rocks of Tyrone," Geol. Mag., 1879, p. 154; and Mem. sheet 26, p. 15.

were probably in progress during these upwellings of molten matter laid hold of the knot of old rocks, and determined its north-east and south-west trend, just as they determined the strike of so many masses in Donegal. It is noteworthy that this trend is that of the "Caledonian" folds generally, which were formed at the close of the Silurian period.

It is also possible that a deep-seated part of the old gneiss became remelted, as Mr. Nolan has suggested,* and supplied part of the material of the Slieve Gallion granite. But the general richness of the metamorphic rocks in ferromagnesian minerals, as now exposed, is an argument against this view. The granitoid veins, however, in the foliation-planes of the gneiss may easily have arisen, at an early date, from the same subterranean caldron as that which later supplied the Slieve Gallion type of granite.

The schists and gneisses of eastern Tyrone exhibit, indeed, sufficient signs of a complex origin. The handsome biotite-gneisses of Evishbrack vary considerably in coarseness, and present all the phenomena that would arise from the parallel intrusion of an aplitic granite into a well foliated but fine-grained biotite-schist. Layers can be selected which are comparable with the pale intrusive gneisses of southern Donegal;† others, in grain and foliation, resemble the "biotite-granulites" of Saxony; others, if detached, would pass for argillaceous sediments rich in iron, which have been rendered micaceous by contact-alteration. In these minutely interlaminated, or, rather, interfoliated rock-types, the biotite can hardly result from paramorphic changes during earth-pressure, as Lehmann‡ has urged in the case of the Saxon granulites. I think that we may see, in this variability of grain and chemical constitution, signs of a double or threefold origin for the mass. (Pl. XXVII., fig. 4.)

The gneiss of Friar's Rock, between the Wolf's Hill and Oughtmore, is a fine-grained granular rock, with a delicate foliation, due to the arrangement of certain of the layers of green biotite. But a great part of the biotite is interstitial, occurring between the grains of quartz, orthoclase, and a repeatedly twinned felspar, which gives the optical characters of andesine.

* *Op. cit.*, Geol. Mag., 1879, p. 159.

† See the present paper, p. 451.

‡ "Entstehung der altkryst. Schiefergesteine," pp. 144–149, and 223.

The biotite, however, is in part included in the quartz. The rest of the biotite forms abundant little knots and aggregates, like those resulting from the absorption of a schist by granite. Though garnet is associated with these aggregates, I see no evidence here of any connexion between its decay and the development of biotite.* The general effect is that of a granular aplite, with a small amount of original biotite, which has invaded a garnetiferous and distinctly basic rock. We shall see later how biotite may result from the action of a granitic magma upon an amphibolite, and how common it is for amphibolites to be found included in granitoid gneiss.

The gneiss of Friar's Rock has been subject to earth-pressures since its consolidation, as is shown by the "strain-shadows" in the quartz between crossed nicols, and by the close-set strings of liquid inclusions, which run in the same direction through the quartz-granules in certain areas, in spite of intervening felspathic grains. On the other hand, the relation of the granular constituents and the biotite shows that little deformation has occurred.

The fine-grained biotite-muscovite-gneiss in Killucan, south-east of the esker-bound lakelet of Lough Doo, outwardly resembles the rock just described; but the biotite is brown, and is uniformly diffused. There are no signs, under the microscope, of mylonitic structure, or of serious deformation of the constituents. Here and there, a coarser vein, with broad decomposed biotite, recalls the granite intrusions in the fine-grained gneiss of Sultanbane.

In the west of Tulnacross, on the road from Charlestown to Dunnamore, the gneiss has, under the microscope, a striking resemblance to that included in the Slieve Gallion granite below Top Heights in the eastern area.† Its brown biotite is carried out in strings and sheets between coarser granitoid layers, and the foliation is more decided than in much of the gneiss on Fir Mountain. In hand-specimens, the rock is absolutely indistinguishable from the gneiss of Craignayarrow, in which the granitic bands are possibly of later origin than the remainder of the mass. The

*See Lehmann, *op. cit.*, p. 223. On interstitial biotite, see Lévy, *op. cit.* ("Granite de Flamanville"), pp. 320 and 339.

† See *ante*, p. 442.

rock in Tulnacross, however, probably well represents the average of those encountered by the later granite in its rise. In Evishbrack, the contrast between successive layers is far more marked; while on Fir Mountain the milder and more schistose type predominates.

Half-a-mile or so south-east of the fairly developed gneisses of Killucan, we have, under Slievemore, rocks with far clearer evidence of dynamo-metamorphic action. "Eye-structure" is obvious under the microscope, whether in the form given to the larger biotites or to the groups of garnet, or to those of quartz and felspar. Colourless mica is also present, as an original constituent of the granitoid layers. Even the latter are now cut up by pressure into compound "eyes," round and between which the biotite-layers flow. While, on the one hand, a rock like this might result from the deformation by pressure of the composite gneiss of Evishbrack, on the other it resembles some of the coarser "Dalradian" schists of the north of Ireland.

To sum up, the gneissic core of eastern Tyrone appears to owe its characters to the intimate intrusion of an ancient aplitic granite magma into pre-existing and fairly basic schists. The latter may have been derived in the first instance from sediments, and may even have become charged with quartz and felspar, under the prolonged influence of contact-metamorphism. Dynamometamorphic action is only locally responsible for the characters of the composite mass.*

V.—General Characters of the Metamorphic Rocks in the Area west of Pettigo.

Some of the literature relating to the gneisses of southern Donegal has been already referred to in the introduction to the present paper. Dr. Charles Callaway,† in 1885, criticised the views of Professor Hull and

* Compare Michel Lévy, "Sur l'origine des terrains cristallins primitifs," Bull. Soc. Geól. de France, 1887, pp. 111 and 113; and "Granite de Flamanville," Bull. carte géol. de France, tome v. (1893), p. 352.

† "On the granitic and schistose rocks of Northern Donegal." Quart. Journ. Geol. Soc. Lond., vol. xli., p. 221.

others, and showed that the granitoid gneiss of northern Donegal was an intrusive rock, and younger than the schists associated with it. Suspicion may thus have fallen on the whole of the Donegal gneiss; and for some years no attempt was made to distinguish any older gneissic series from the igneous group which included the granite of Barnesmore or Barnesbeg.

In 1862, however, Mr. R. H. Scott* had pointed out that the gneiss near Castle Caldwell on Lough Erne was traversed by granite veins, and that similar veins, of "typical Donegal granite," cut the gneiss at Black Gap, west of Pettigo. He also noted† that the "Donegal granite" included blocks of gneiss, though he concluded from this that the granite represented an extreme phase of metamorphism, and that the two series were identical. Dr. S. Haughton‡ emphasised the distinctness of the granite veins and the gneiss, as the result of a tour with Dr. Scott, in 1862; and Mr. W. Harte,§ in 1867, referred to numerous cases in which blocks of gneiss are included in the granite of Donegal.

In 1891, Sir Archibald Geikie‖ wrote the chapter describing the Archæan Rocks included in sheet 32 of the Geological Survey of Ireland, and Mr. Teall supplied valuable petrographic descriptions. The microcline-granites and so-called "pegmatites" of southern Donegal were included in the archæan series; but it was pointed out that some of them had intruded after the gneiss had assumed its foliation. A series of hornblendic rocks, sometimes "full of pegmatite veins," was described as intrusive, and as "younger than the older foliation of the gneiss, but more ancient than the subsequent movements which gave rise to the later foliation."¶ A boundary was then drawn between the more gneissic series and the

* "On the granitic rocks of the south-west of Donegal," Journ. Geol. Soc. Dublin, vol. ix., p. 286.

† "On the granitic rocks of Donegal," *ibid.*, vol. x. (1864), p. 19.

‡ "Experimental researches on the Granites of Ireland, part iii." Quart. Journ. Geol. Soc. London, vol. xviii. (1862), pp. 403 and 407.

§ "Crumpled granite beds in the county of Donegal." Journ. R. Geol. Soc. Ireland, vol. i., p. 144.

‖ Mem. sheets 31 and 32, pp. 5, 10, and 39.

¶ *Ibid.*, p. 13.

"Dalradian"* schists, quartzites, and limestones, farther north. This boundary, though not recognised in 1888,† appeared upon the new edition of sheet 24 in 1891.

A brief account of the Pettigo rocks appears on p. 59 of Messrs. M'Henry and Watts's "Guide to the collections of rocks and fossils of the Geological Survey of Ireland," issued in 1895.

The area under consideration forms a comparatively low moorland, stretching 12 miles northward from Lough Erne, and about 10 miles from Pettigo towards Ballintra. Its southern edge thus lies in the county of Fermanagh, and its north-eastern in the county of Tyrone. The rocks have probably been involved in the "Huronian" folding of Bertrand, and certainly in the "Caledonian" folding. The Carboniferous synclinals, penetrating the gneiss on its western edge, as shown upon the Survey map, clearly indicate that some further folding took place from south to north in this area during the "Hercynian" movements. The occasional dykes of dolerite, similar to those occurring, with a north-west and south-east trend, in the adjacent Carboniferous areas, are doubtless of Cainozoic age, and give us some suggestion of the "Alpine" movements, which made, however, little impression on the mass. One of these dykes traverses the red gneiss and the granite veins in a little quarry north of Carn; two others appear across a field in the angle of roads east of Glashagh Bridge, and are shown upon the Survey map.

The older rocks with which we have to deal can be well appreciated from Mr. Teall's‡ descriptions. The gneiss along the shore of Lough Erne is almost free from ferromagnesian constituents, and shows its foliated structure only by light grey bands, running in undulations through a white ground formed of quartz, kaolinised felspar, and small scales of muscovite. The grey bands are caused by the local accumulation of granular quartz, and the diminution of the felspar, throughout certain layers of the rock. Their contorted forms are probably due to movement under pressure during the last stages of crystallisation in the mass, like the wavy forms due to

* Sir A. Geikie, Quart. Journ. Geol. Soc. London, vol. xlvii., *Proceedings*, p. 75.

† Mem. sheet 24, p. 13.

‡ Mem. sheets 31 and 32, p. 39.

flow-structure in viscid lavas. Granite veins, with red felspars, cut through the gneiss, running across its foliation.

Here and there biotite is a constituent of this gneiss, and is spread out along certain foliation-planes; but the rock, as a whole, is one of great simplicity. It is a type of the pure white granular gneisses that appear also at Carn, at Lough Derg, and very generally across the moorland; muscovite, however, is more prevalent along Lough Erne than in the northern areas.

In sharp contrast, we have the amphibolites, dark green or black rocks, with well-marked foliation in places; some contain garnet, some pale green pyroxene in addition. The latter type is properly classed by Mr. Teall with the eclogites. It seems probable that these rocks, which are nowhere of broad extent, form the series regarded in the Survey memoir as intrusive in the gneiss.

Lastly, there are the veins of coarse microcline granite, which cut the amphibolites and the gneiss, and which come up most abundantly at the junction of these two types of rock. These veins cannot be regarded as an integral part of the metamorphic mass; and they recall strikingly the similar veins in Tyrone, which we have already correlated with the granite of Slieve Gallion. In southern Donegal they may similarly be of "Caledonian" age, and are probably connected with the upwelling of the granite which forms so bold a feature at Barnesmore. This granite cuts the Dalradian schists, and is thus later than they, but is still of doubtful age. As Messrs. M'Henry and Watts* state, "it may conceivably be of Tertiary age"; but its relation to the Cainozoic dykes of pitchstone, andesite,† and dolerite which traverse it would refer it, with greater probability, to the epoch of the Caledonian movements.

The gneisses rich in biotite, which occur freely in our area, have been omitted from the above description, since they graduate on the one hand into the amphibolite series, and on the other into the white gneiss. Their position will be best understood from the study of a few special localities.

* *Op. cit.*, p. 72.

† See descriptions of these rocks by Prof. W. J. Sollas, Sci. Proc. R. Dublin Soc., vol. viii. (1893), p. 87.

VI.—Relations of the Rocks in the Gneissic Area of Southern Donegal.

On the slopes north of the old church of Carn, between Pettigo and Lough Erne, the white gneiss appears predominantly. It is a fresh looking granular aggregate of quartz and colourless orthoclase, with minute dark green or black biotite flakes marking the foliation here and there. Occasionally the biotite is accumulated, and produces a darker type of rock; but the more extreme instances of this darkening are clearly connected with the proximity of masses of amphibolite. Under the microscope, the felspars display ovoid lenticular forms; but there are no signs of stress and elongation since the consolidation of the rock. The intrusive granite of Cregganconroe* exhibits crystals of the same form, which owe their characters to igneous flow.

This gneiss in the townland of Carn is associated with tough dark amphibolite, which appears as "eyes" of varying dimensions, wrapped about by gneiss. This relation is particularly apparent in the quarry at the fork of the old and new roads from Pettigo to Lough Derg, where the "eyes" are numerous, and 15 to 30 cm. long. At any point, however, on the slopes of Carn, the gneiss may be seen intruding into the amphibolite. Flakes of the dark rock become included in the gneiss, producing layers of biotite at the contact-zone. The gneiss itself thus comes to contain filmy streaks of biotite, and passes locally into a handsome variety, with strongly contrasted foliation-layers. Here and there the parallel intrusion of gneissic veins into the amphibolite produces a compound rock in which the dark materials predominate (Pl. xxvii., fig. 6).

Microscopic study of the junction shows that brown-green biotite developes as a contact-mineral, forming layers parallel to the junction and therefore to the pre-existing foliation of the schistose amphibolite (Pl. xxvi., fig. 5). Sphene is also frequent along the junction. In the centre of one

* See *ante*, p. 439, and Pl. xxvi., fig. 1.

of its aggregations a dark brown patch is seen, which is probably allanite.* Now and then an "eye" formed of a single crystal of amphibole, two centimetres or so long, may appear in the gneiss, and this will be covered with a film of biotite, which tails out into the gneiss on either hand.

The occurrence of biotite as a contact-product of hornblende, or, if we trace it back, of pyroxene,† has been recently emphasised by Mr. Parkinson.‡ The admirable observations of Messrs. Hill and Bonney§ on the inclusion of hornblende-schist in gneiss in Sark provide a yet closer parallel to the instances now under discussion. Lehmann‖ also attributes part of the mica which forms foliation-layers in the granite of Böhrigen to the absorption of biotite-schist, and part to the absorption of amphibolite. Doelter,¶ moreover, in his experimental work, has melted aluminous hornblende and augite with magnesium and sodium fluorides, and has produced biotite. Under similar circumstances, pyrope and almandine also yielded biotite of the Vesuvian type. Seeing that the amphibolites of Carn are often rich in garnet, various sources may be suggested for the biotite which enriches the pale gneiss.

Occasionally, broader veins of the gneiss intrude into the dark rocks, which then become locally more coarse-grained and dioritic. This agrees with the observation of M. Lévy** as to the production of diorites by the extreme metamorphism of his basic "cornéennes" in Brittany.

The amphibolites in Carn vary somewhat, some being slightly pyroxenic,

* Allanite is more commonly included in ordinary epidote (see Flett, "Scottish rocks containing orthite," Geol. Mag., 1898, p. 390). Teall thus observed it in southern Donegal (Mem. sheets 31 and 32, p. 41). But it often occurs in rocks that contain sphene, and has been seen to surround that mineral in its turn (Iddings and Cross, "Occurrences of Allanite," Am. Jour. Sci., vol. xxx., p. 110).

† See Sollas, "Granite, &c. of Barnavave," Trans. R. I. A., vol. xxx., p. 493.

‡ "Intrusion of granite into Diabase at Sorel Pt." Quart. Journ. Geol. Soc. Lond., vol. lv., pp. 440, 441, 443, &c.

§ "On the Hornblende-schists, &c., of Sark." *Ibid.*, vol. xlviii. (1892), pp. 128–132.

‖ "Ent. der altkryst. Schiefergesteine," p. 63.

¶ "Ueber die künstliche Bildung von Muscovit, Biotit, und Lepidolith." Neues Jahrb. für Min., &c., 1888, Bd. ii., p. 178.

** *Op. cit.* ("Granite de Flamanville"), p. 329.

others entirely hornblendic. Garnet is often present, and is included ophitically by the dark green amphibole. Quartz and granular triclinic felspar occur intertangled, almost pegmatitically, with the larger amphiboles, and also forming an interstitial groundwork.* The hornblende has included a fair amount of rutile, which is rarely found in the quartz or felspar. An epidote, colourless in thin section, occurs in some masses, but plays a larger part in the constitution of the amphibolites of Lough Derg. This epidote occurs also in the biotitic contact-layer formed at the junction of the amphibolite and the gneiss, and confirms the derivation of this layer from the amphibolite.

Veins of granite with red orthoclase, probably offshoots from the later granite, appear here and there in Carn, and even intrude in parallelism with the undoubted offshoots from the gneiss. In a quarry lower down, just west of the new road, they come in abundantly, giving a red aspect to an otherwise fine-grained grey biotite-gneiss. Part of the ovoid grains of felspar in this gneiss, and the coarser crystals in the granite veins, consist of microcline, and there is little to distinguish the two types of rock except their very different aspect in the field.

The light and dark rocks of the district preserve the same relations, as one traces them up to the south shore of Lough Derg. Here a series of beautiful "eyes" of amphibolite, often ten or fifteen feet in length, lie in the gneiss, which flows round them, and which becomes more micaceous and flaggy near the junction (Pl. XXVII., fig. 1). The gneiss is a remarkably pure aplitic rock, with films of very dark biotite, which is almost opaque in section (Pl. XXVI., fig. 3). The biotite serves in most parts to just indicate a foliation; but the form of the felspars is not influenced by flow, either arising from pressure or from movement in a molten mass. Near the amphibolite "eyes," however, flakes of the dark included rock become drawn out into foliation-films †; veins of gneiss, with distinct if delicate flow-structure, penetrate along the planes of weakness in the included

* This recalls the contact-structure observed by Lévy between biotite and quartz at Ozette, near Limoges ("Granite de Flamanville," p. 344).

† Compare also A. C. Lawson, "Geol. of Rainy Lake region," Ann. Rep. Geol. Surv. Canada, 1887, pl. vi., p. 138F.

mass; and all the phenomena of an igneous junction, accompanied by flow, are reproduced (Pl. xxvii., fig. 5). The gneiss, which is elsewhere hardly distinguishable from a well preserved and fine-grained granite, here becomes distinctly foliated, and is easily separable into vertical layers.* The flow-planes run roughly north-west and south-east near the Ferry House on Lough Derg, and the "eyes" thus have their longer axes directed towards the lake.

A section of a vein traversing the amphibolite shows that the gneiss has become charged with colourless epidote, and contains separated flakes of brown biotite; similar epidote, answering all applicable optical tests, is abundant in the amphibolite, while brown mica occurs sparsely. There is no doubt, then, as to the source of the epidote in the vein; and the green hornblende of the amphibolite may have become converted into biotite. A few garnets at the junction are, no doubt, also derived from the amphibolite; but the garnets of the latter rock fuse so readily before the blowpipe that it is difficult to believe that any great number could escape destruction in the intrusive magma. When once destroyed, moreover, they would not be likely to re-appear in their original form, as the experimental researches of Doelter and Hussak show.† As a matter of fact, the isolation of the "eyes" of garnet-amphibolite in the gneiss of Lough Derg implies a considerable amount of absorption and loss of bulk; but the gneiss round about is by no means garnetiferous.

Mr. Teall‡ has already described two of the amphibolites of Lough Derg. Some contain minute granular pyroxene, intimately associated with brown-green hornblende, which is probably a paramorphic product, and which occurs most generally in large ophitic crystals, including garnet, and interlocked with quartz and clear and colourless felspar. The crystals of colourless epidote, with their long orthodiagonal axes lying in the foliation planes of the schistose amphibolite, are a feature of the rock when

* This is probably a similar structure to that noted by Mr. Harte as a thin vertical stratification in the granite of Dunglow (*op. cit.*, Journ. R. Geol. Soc. Ireland, vol. i., p. 144).

† "Synthetische Studien," Neues Jahrb. für. Min., &c., 1884, Bd. i., pp. 171 and 172. Also, *ibid.*, 1888, Bd. ii., p. 178. Compare Lacroix, "Enclaves des roches volcaniques," p. 574, on the ready disappearance of garnet in basaltic magmas.

‡ Mem. sheets 31 and 32, p. 41, descriptions 543 and 544.

garnet is comparatively scarce. The same fact is observable in Carn; moreover, the garnetiferous varieties of the amphibolite are typically less schistose than those that are rich in epidote.

If we make a complete traverse of the gneissic area, from Pettigo to Laghy, the same relations are everywhere observable between the various types of rock. At a small quarry beside the main road in Fincashel, the banded muscovite-gneiss of the Lough Erne type appears, but with pinker felspar. It is cut by the prevalent coarse granite veins. At the quarry opposite Mountain Lodge, a great "eye" of amphibolite is seen to be wrapped round, and in part still covered, by the pale gneiss. The amphibolite varies in character, from a beautifully garnetiferous eclogite (Pl. xxvi., fig. 6) to micaceous varieties, and to a coarse and almost dioritic hornblende-schist. Handsome veins of pink coarse-grained granite, sometimes with true graphic (pegmatitic) structure, cut across the foliation-planes of the amphibolite and of the surrounding gneiss. The gneiss is modified by the penetrating offshoots of these veins, as at Craignagarrow, in the county of Tyrone; while in places a vein follows and emphasises the contorted banding of the rock. This banding is due to the inclusion by the gneiss of flakes from the amphibolite, and their conversion into folia of biotite.

In microscopic section, the pegmatitic veins show here and there strings of small biotite crystals, associated with pink garnet (Pl. xxvi., fig. 4). At times, the garnet lies in an envelope of biotite, which is distinct from it, and which does not arise from its alteration. I have no doubt that these minerals are derived from the adjacent amphibolite, and that the mica is here again a product of alteration from the hornblende. The junction of the later granite with the amphibolite of Mountain Lodge only repeats the features of the more ancient series of intrusions, and strengthens the arguments concerning them. In both cases, garnet is likely to be preserved only in the contact-zone, where flakes of the invaded rock have undergone only partial absorption.

The eclogite in the great "eye" at Mountain Lodge contains, as seen in section,* pale green pyroxene, some brown biotite, and green amphibole

* Compare Teall, Mem. sheets 31 and 32, p. 40, descriptions 533 and 534.

(Pl. xxvi., fig. 6). The amphibole has developed paramorphically from the pyroxene, but in ophitic and spreading crystals, which wrap round the garnet. There is no epidote in this richly coloured rock, and the clear quartz and felspar form, as usual, an interstitial feature.

Farther west, in the townland of Belalt North, the hummocky ground through which the Black Gap has been cut is composed of a gneiss with muscovite and biotite, well foliated, and gnarled in structure. The folds of the foliation are often bent over and recumbent, and shearing has taken place, whereby they have been cut through and displaced.* The biotite, which darkens this fine-grained gneiss, is accumulated locally, and is by no means constant; occasionally, and very suggestively, dark gneiss occurs in eye-like patches in the paler variety. Immediately to the west of the Gap, true amphibolite is seen in the gneiss, the relations being obscured by later granite and by faulting; but the foliation of the gneiss runs, as usual, parallel to the contact with the amphibolite. It is difficult to escape the conclusion that, even in this broad area, the darkening of the gneiss is a phenomenon of igneous contact and intermixture. The later shearing of the folds of the foliation may, of course, be due to earth-movement; but is it really more than the result of final movements in a consolidating mass, such as those which produce brecciation in the fluidal layers of many lava-flows?

A section of the dark gneiss of Belalt North shows an unusual development of muscovite; but it has arisen simultaneously with the biotite, and is often included in the latter mineral. The plates of muscovite lie at all angles in the groups of biotite, and often across the general foliated arrangement of the rock. There is no satisfactory evidence that any of the minerals were arranged by pressure acting subsequently to the consolidation of the mass. It is possible that the introduction of so much aluminous matter from absorbed blocks of amphibolite has checked the formation of orthoclase in this case, and has promoted that of muscovite. Both quartz and orthoclase occur, but far more sparsely than in the typical gneiss of southern

* Sir A. Geikie has called attention to this structure (Mem. sheets 31 and 32, p. 12). He regards the micaceous layers in the gneisses as due to shearing (*ibid.*, p. 13), a view which finds support in Lehmann's observations, wherever dynamic action is conspicuous.

Donegal. I cannot ascribe the abundant and matted flakes of muscovite to the alteration of other minerals, under pressure or under prolonged chemical action. The association of small garnets with the biotite indicates that the latter mineral is a product of absorption and recrystallisation from the garnetiferous amphibolites, as is the case in the pegmatite veins at Mountain Lodge, and the muscovite clearly belongs to the same period of consolidation as the biotite. It must be admitted that muscovite is not seen in this ar as a direct product of the intermingling of the gneiss and the amphibolites, but it is one of the commonest products of contact-metamorphism in argillaceous rocks, and such rocks may possibly have been associated with the hornblendic series in Belalt North.

The biotite-gneiss of this townland, by its arrangement in the paler gneiss, reminds us, on an almost regional scale, of the biotite patches in the intrusive granite of Craignayarrow.* Without straining the intrusive view, the small part played here by dynamic action makes us seek out another cause for the gneissic structure of the district.

The gnarled gneiss, with its contorted foliation, so similar, as Scrope† and Darwin‡ long ago pointed out, to the flow-structure of a viscid molten mass, recurs in the bosses between the lakes in the bogland west of the Black Gap.

In the east of the townland of Shannagh, there is a beautiful example of a large amphibolite "eye," overwrapped by pale gneiss on its north-west side, and penetrated by pink granite veins. As usual, this granite comes up most abundantly about the junction of the two older types of rock, and traverses them both (Pl. xxvii., fig. 2). Similar features are seen here on both sides of the main road. We may well conclude our illustrations of the gneissic moorland of southern Donegal with this highly typical example of its structure.

* See *ante*, p. 443.

† "Considerations on Volcanos" (1825), p. 226.

‡ "Geol. Observations on S. America" (1846), Minerva edition, p. 440.

VII. The Origin of the Amphibolites and Pyroxenites included in the Gneiss of Southern Donegal.

An extensive series of instances is now known, in which granite or gneiss includes blocks of amphibolite or pyroxenite. It would seem, indeed, firstly, that these materials are specially visited by granite intrusions; or, secondly, that they are liable to be preserved when other rocks become melted down and completely absorbed; or, thirdly, that various types of rock give rise to amphibolite or pyroxenite by contact-alteration, and thus pass all the more completely into rocks of that group when included in a granite magma. We have, however, to recall a still greater number of instances where dark *micaceous* patches, the so-called segregations,* lie in granite as the relics of inclusions of schist or dolerite; the amphibolite patches may occur more readily to our minds, merely because greater attention has been paid to them. None the less, it must be admitted that the literature of the subject goes far to support our third suggestion.

M. Lévy† has usefully reviewed many of the cases where gneisses, amphibolites, cipollinos, and intrusive granites, are associated in the field. In 1883‡ he showed how actinolitic amphibolites, containing orthoclase and quartz, arise from the intrusion of granite into coarse basic diorites. In 1890 M. Lévy§ stated that pyroxene and amphibole schists have been formed in Auvergne from the penetrating metamorphic action of "granite ambiant" in limestone. In 1893‖ he extended these observations to the contact of granite with sedimentary strata in Brittany, and pointed out that pyroxenic and garnetiferous "cornéennes" occur where limestone is invaded, the alkaline

* See the admirable discussion by Sollas, "Relation of granite to gabbro of Barnavave," Trans. R.I. Acad., vol. xxx. (1894), p. 502. Also Duparc and Mrazec, "Recherches géol. et pétrograph. sur le massif du Mont-Blanc," Mém. soc. phys. et d'hist. naturelle de Genève, t. xxxiii. (1898), p. 55.

† "Note sur la formation gneissique du Morvan." Bull. Soc. Géol. de France, 3me. série, t. vii. (1879), p. 857. Compare Rosenbusch, "Elemente der Gesteinslehre" (1898), p. 511.

‡ "Roches éruptives basiques cambriennes du Mâconnais et du Beaujolais." Bull. Soc. Géol. de Fr., 3me. sér., t. xi., p. 296.

§ "Excursion à Aydat." *Ibid.*, p. 916.

‖ "Granite de Flamanville," Bull. Serv. carte géol. de France, t. v., p. 337.

elements necessary for the formation of felspars being imported by mineralising agents from the granite. Prof. B. K. Emerson* has also recently considered the association of limestone and amphibolites, and has dwelt on certain passage-phenomena as indicating the derivation of the latter, by general metamorphism, from the former. He admits, however, the possible igneous origin of some of the amphibolites studied by him.

The development of pyroxenes, amphiboles, epidotes, and scapolites by the contact of granite with limestone is well discussed by Rosenbusch,† and the extraordinary extent to which silicates have arisen in the limestone blocks of Monte Somma shows how far deep-seated contact-metamorphism may proceed in altering the facies of a rock.

The conversion of diorites, gabbros, and altered basic igneous rocks of all kinds into hornblende-schists provides convenient material for the production of amphibolites by further "mineralising" action. Scheerer‡ attributed the "trap-granulites" of Saxony to the action of granite on the overlying clay-slate layers, or to its intermingling with basic igneous rocks. Lehmann§ disputed the reasoning in this particular instance; but his own work goes far to support its applicability to other cases. A very well known example of the alteration of hornblende-schists, of igneous origin, into granular felspathic amphibolites is provided by the inclusions from the Keewatin (Lower Huronian) series that lie in the gneiss near Lake Superior.‖ MM. Duparc and Delebecque,¶ moreover, have shown how amphibolites, consisting of a very pleochroic amphibole, orthoclase, some oligoclase, sphene, and magnetite, have arisen in the Western Alps from the metamorphism of uralitised gabbros.

Gabbros (euphotides) and diabases of all kinds have been traced into

* "Geology of Old Hampshire County, Massachusetts." U. S. Geol. Surv. Monograph xxix. (1898), pp. 282, 297, and 300.

† "Mikroskop. Physiographie d. mass. Gesteine," 3te. Auflage (1896), p. 96.

‡ "Uber die Genesis der Granulite," Neues Jahrb. für Min., &c., 1873, pp. 688–690.

§ "Ent. altkryst, Schiefergesteine," p. 235.

‖ Lawson, "Rainy Lake region," Ann. Rep. Geol. Surv. Canada, 1887, p. 133F.

¶ "Sur les gabbros et les amphibolites du massif de Belledonne," Comptes rendus, t. cxviii., p. 674.

typical and even garnetiferous amphibolites by S. Franchi,* who attributes their metamorphism in the Western Alps to prolonged heating and pressure, acting when the igneous rocks were lowered to a considerable depth beneath Triassic and Jurassic strata.

A considerable range of materials may thus provide pyroxenites and amphibolites; and well developed rocks of this kind may even occur, through previous metamorphic action, in a schistose series, being ready made, as it were, for inclusion in any invading magma.†

Whence, however, were the amphibolites derived, which occur so commonly as "eyes" in the granite-gneiss of southern Donegal? They are clearly, as in American and other instances, to be sought for in some overlying series. If we push our observations northward, towards the region of Dalradian schists, we find typical fine-grained gneiss, like that of the intrusive bands in Carn, on the descent into the county of Tyrone, between Pettigo and Glashagh Bridge. Richly biotitic bands are, however, frequent in this gneiss, forming, with continuous bands of quartz, contorted foliation-layers. But the gneiss soon loses its predominance in this region. Half-a-mile farther north, aplitic veins have succeeded in streaking out a garnet-amphibolite, and have separated its individual constituents in many places during flow; but it is clear that whole sheets of the original rocks remain intact. One of these sheets, looking like an interfoliated gneiss-vein in the field, proves to consist of quartz, epidote, and a ferriferous calcite, in fairly foliated layers. The calcite turns brown-black before the blowpipe, and yields a yellow solution in hydrochloric acid; but the proportion of iron in it is not enough to render its reduced particles magnetic. The appearance of calcite in this series of schists prepares us for the true limestone in the Dalradian series of Killeter.

Close at hand, on the same pass, are muscovite-biotite-quartz-schists, with a little granular felspar and garnet, which are quite distinct from the

* "Sopra alcune metamorfosi di eufotidi e diabasi nelle Alpi Occidentali," Boll. R. Com. Geol. d'Italia, vol. xxvi., p. 200; also "Prasiniti ed amfiboliti provenienti dalla metamorfosi di roccie diabasiche presso Pegli, &c.," Boll. Soc. Geol. Ital., vol. xv. (1896), p. 169.

† Compare those described in Ann. Rep. Geol. Survey of Gt. Britain, 1894, p. 280, and "Summary of Progress," *ibid.*, 1897, pp. 41 and 42.

intermingled rocks of the Black Gap, although their mineral constitution may be fairly similar. These northern rocks, with their glancing foliation-surfaces, are typical mica-schists, such as may be produced by pressure and high temperature, at the expense of ordinary sediments. There are signs of deformation and "phacoidal" structure, due to pressure; but a number of the biotite crystals have managed to develope across the general foliation-sheets; their edges thus appear on the surfaces of these layers like little black prismatic forms. Delicate granite veins, with pink felspars, penetrate this rock, and may belong to the later granite of the district, rather than to the gneiss. Coarse schists of the same kind are exposed near the end of the ridge south-west of Glashagh Bridge, and are here even more like altered sediments. Quartz and felspar are insignificant in the mass, compared to the two micas and the abundant garnet. Pyrite is also common. Much of the biotite is altered to chlorite, and a true chlorite-schist occurs farther north along the spur. This consists, however, of chlorite and calcite, with only a little minutely granular quartz and felspar in the groundwork. Calcite is, from this point on, a frequent constituent in the schists.

Down in the hollow of the Glashagh Burn, the fine-grained granitoid gneiss again appears. At no point does it lie far beneath us, though we seem to have reached an overlying metamorphic series. In the quarry at the junction of roads east of Glashagh Bridge, the mica-schist is described by Mr. Teall* as "containing lenticles (? deformed pebbles) of granulitic quartz. . . . This rock has affinities with some of the 'green schists' in the central and southern Highlands of Scotland." It has gneissic characters here and there, and a good deal of aplitic granitoid material appears in it in section; but the suggestion of old pebbles in it has caused the line between the older rocks and the Dalradians to be drawn on the Survey map through this quarry. Mr. Teall,† however, classed the schist at this point with that from the south of Glashagh Bridge, and observation in the field certainly supports his view. The boundary, if it can be drawn at all, is obviously a tentative one, and may be carried farther south; it seems

* Mem. sheets 31 and 32, p. 41, description 555.

† *Ibid.*, p. 11.

clear that the fact of the intrusion of the gneiss in granitoid sheets into at least some members of an overlying series may profoundly modify our views, *or may make us seek for some line of demarcation between an older and a younger series within the Dalradian schists themselves.*

Can such a line be found as a base to the "newer schists," these Dalradians, of southern Donegal? That is a matter for extended mapping, and for one who has wider experience of the Dalradian area to the north. I have a strong suspicion, however, that the pyroxenites and amphibolites which are embedded in the gneiss may be derived from the basement beds of the overlying schistose series. Indeed, I venture to prefer this to any other explanation, in view of the fact that these dark rocks are not intrusive in the gneiss, that they are derived from some pre-existing schists, whether of igneous or sedimentary origin, and that the schists still found above the gneiss on its north side provide material of suitable mineral constitution.

The prevalence of "hornblende-rock" and "hornblende-schist," probably of igneous origin, within the Dalradian series, has been well remarked by Mr. Kilroe.* The bands south-west of Killeter are specially referred to. In section, one of these schists, very rich in foliated and silky-looking actinolite, exhibits a suspicious little vein of aplitic granite, cutting across its foliation layers. Is this series also invaded by the underlying gneiss? Between two sheets of hornblende-schist south-west of Killeter, there is a rock composed of granular quartz and partly muscovitised felspar, these minerals being often interlocked, as in so many aplites. A little biotite, now altered to chlorite, is also present. This rock seems to have escaped the striking dynamic metamorphism of its surroundings, and may well be a later igneous intrusion. But its origin is, I fear, indeterminable. It might, indeed, be easily mistaken for a quartzite in the field.

The mica-schists of the same locality contain a fair amount of pyrite. They are often coarse, and graduate into gneiss; but such rocks are admitted in the Grenville Series of Canada,† and are regarded as of

* Geol. Surv. Ireland, Mem. sheet 24 (1888), p. 22.

† See Van Hise, "Principles of N. American Pre-cambrian Geology," 16th Ann. Rep. U. S. Geol. Survey (1894–5), p. 767.

sedimentary origin. Recent work by Mr. J. B. Hill* in the neighbourhood of Loch Awe, to mention no other instances, tends to show that intense metamorphism may produce rocks of an almost "fundamental" aspect from well marked sediments. In this matter we may note a gradual return towards the uniformitarian views held early in the present century.

The majority of the rocks of Killeter show marked effects of pressure-metamorphism ; when gneissic they are fine-grained, and, in the lenticular character of their aggregates of granular quartz,† and in the grouping of the micas round them, differ from the gneiss that prevails in the district to the south. While we may admit the general sedimentary characteristics revealed in the rocks traversed between the boundary of Tyrone and the village of Killeter, we feel that these same rocks would provide good material for the pyroxenites and amphibolites that are embedded in the southern gneiss. At any rate, if not directly Dalradian, these amphibolites must be derived from the floor on which the Dalradian series was laid down.

VIII.—General Conclusions from the Examination of the Metamorphic Rocks of Eastern Tyrone and Southern Donegal.

The study of the two areas above described proves the existence of an ancient schistose series of rocks, foliated by dynamic metamorphism. This is the oldest recognisable series in these areas.

In eastern Tyrone, the occasional gneissic character of this metamorphic series has probably been induced by the intrusion of a granite magma. The structures due to dynamic action are usually lost in the new flow-structures set up, and a large part of the axis of old rocks shows, in consequence, the phenomena of interpenetration and intimate mixture

* Quart. Journ. Geol. Soc. Lond., vol. lv. (1899), p. 470.

† This quartz, with its uniform closely-set granules, and yellow stainings between them and in the cracks, suggests cordierite or scapolite under the microscope. Optical and blowpipe tests exclude both these minerals. The staining is due to the decomposition of pyrite.

that we are now accustomed to look for near the surface of a granite dome.*

The gneisses thus produced, as well as the less altered schists, are traversed by and included in the granite of the Slieve Gallion type, which also cuts an overlying basic igneous series.

The surface of the Tyrone moorland has not been sufficiently worn down by denudation for the exposure of the older granitic material in a pure state. This appears, however, in southern Donegal, and has been correlated by some authors with the Lewisian gneiss of Scotland.

Throughout southern Donegal, this granitoid gneiss is seen to be intrusive in an amphibolite series, and to include large and small masses of that series. The pure quartz-felspar-muscovite gneiss, often nearly an aplite, becomes rich in biotite at the junctions, and receives a foliated structure, which is due to flow and not to pressure-metamorphism.

The relations of the rocks in southern Donegal are precisely those noted in many localities in N. America, between the "Laurentian" gneiss and amphibolites, or other rocks, belonging to various overlying series.†

Despite numerous arguments to prove that the Laurentian gneisses as a whole are fundamental, and "originally existed as the floor upon which the Huronian was deposited,"‡ large portions of the group have been already relegated to the post-Huronian intrusive series.

Lawson§ has pointed out that "while both the Coutchiching and Keewatin rocks afford ample evidence of having yielded to pressures and

* The extreme of such action is described by M. Lévy, when he says that in the zone of absolute contact, a few metres thick, we may have synthetic leptynites, mica-schists, gneisses, amphibolites, &c., at the expense of Carboniferous, Devonian, or Silurian strata ("Granite de Flamanville," p. 338). The beautiful exposition by M. Barrois of the basin of Ménez-Bélair shows what changes are produced in a sedimentary district by differential absorption along the walls of granite caldrons (Ann. de la Soc. Geol. du Nord, t. xxii. (1894), pp. 232, 247, 249, 282, and 342).

† See Van Hise, "Correlation-papers—Archæan and Algonkian." Bull. U. S. Geol. Survey, No. 86 (1892), pp. 34, 66, 164, 237, 252, and 383.

‡ G. M. Dawson, "Address to British Association." Nature, vol. 56 (1897), p. 399.

§ *Op. cit.* ("Rainy Lake region"), p. 131F.

earth stresses, the Laurentian gneisses do not, except very locally, and to an insignificant extent." The same may be said of the crushed Dalradian series, in contrast with the intrusive gneiss, in southern Donegal.

Hence it is natural to suppose that the Dalradian rocks are the oldest now remaining in this district; either their basement layers, or still older schistose beds on which they were laid down, have become broken up, and in part absorbed, giving rise to the dark inclusions of pyroxenite and amphibolite, and to the foliated layers of biotite, which occur so frequently in the granitoid gneiss, and which impart to it its most marked gneissic characters.*

The whole metamorphic and igneous group, excluding the veins of later granite, may well be of Archæan age. It can hardly be younger than the series of schists and quartzites in the counties of Galway and Mayo, above which Ordovician beds are now known to lie, these beds being separated from the metamorphic floor by a considerable unconformity.† It is of importance to remember that Dr. Callaway‡ showed in 1887 how gneiss has been formed in Galway by the intrusion of granite into a series rich in amphibole. The wide significance of his paper may not have been at once appreciated; but the relation described as existing between the two types of rock will probably be found to prevail throughout the whole of north-west Ireland.

The same relation is now, moreover, known to exist in the complex mass forming the Lewisian gneiss of Scotland. Amphibolites occur "as lumps in the gneiss" of many localities§ in the western Highlands; and Sir A. Geikie‖ has given us a vivid picture of the varied nature, and generally eruptive

* Compare the important work of J. J. Sederholm, "Über eine archäische sedimentformation im südwestlichen Finland, &c." Bull. de la Comm. Géol. de la Finlande, No. 6 (1899), pp. 139 and 155.

† Ann. Rep. Geol. Survey United Kingdom for 1896, p. 50.

‡ "Alleged conversion of crystalline schists into igneous rocks in County Galway." Quart. Journ. Geol. Soc. Lond., vol. xliii., pp. 521 and 523. Also "On the origin of some of the gneisses of Anglesey," *ibid.*, vol. liii. (1897), p. 353.

§ Ann. Rep. Geol. Survey for 1894, p. 280; and "Summary of Progress Geol. Survey for 1897," p. 40.

‖ "Ancient Volcanoes of Great Britain" (1897), vol. i., pp. 115 and 117.

character, of what was once known as the Fundamental Gneiss. But there is no doubt that the rocks invaded by the gneiss are of pre-Cambrian, and even pre-Torridonian, age; and that the intrusion of the gneiss into them is likewise pre-Torridonian. The analogy is altogether in favour of our placing the series in southern Donegal, taken as a whole, equally among pre-Cambrian rocks, as Sir A. Geikie stated in 1891, even if we have to reverse the relative age of its two distinct types of material.

From the point of view of physical geology, the questions raised by these Irish areas have very considerable interest. Their details tend to confirm the opinion that gneisses may be produced by admixture along surfaces of igneous contact, a view that has been so definitely maintained by M. Michel Lévy. Contact-metamorphism, in such cases, occurs indeed upon a regional scale. As M. Lévy* remarks, microscopic investigation attributes "au métamorphisme de contact et de pénétration une importance que Delesse avait surtout attribué au métamorphisme général." Such conclusions rest, moreover, not only on microscopic work, but on solid observations in the field. The Protogine of the Western Alps† has thus "granitised" the adjacent schists, instead of being itself a product of their progressive metamorphism; the micaceous slates of Newfoundland‡ pass down by perfect gradations into gneiss, and then into granite, because of the regional effect of the intrusion of granite along their base. The variability in the composition and mineral constitution of the gneissose granites of Donegal was long ago pointed out by Dr. Haughton; § we may account for it by supposing that we are at some points farther than others from the surface of the original intrusive mass. Whole areas of biotitic matter remain in places undiffused; in other places, not far distant, the covering of schistose rocks still remains intact;

* "Sur l'origine des terrains cristallins primitifs," Bull. Soc. Géol. de France, 3me. sér., t. xvi. (1887), p. 113.

† Lévy, "Granite de Flamanville," p. 338, footnote.

‡ Van Hise, *op. cit.* Bull. U. S. Geol. Survey, No. 86, pp. 248 and 252.

§ "Exp. researches on granites of Ireland, part iii.," Quart. Journ. Geol. Soc. London, vol. xviii (1862), pp. 408-410. *Cf.* Duparc and Mrazec, *op. cit.*, p. 165.

in others, as in southern Donegal, denudation has exposed the lower and the purer levels of the gneiss. (See fig. 1.)*

FIGURE 1.

Ideal section through a series of shales, quartzites, limestones, and basic igneous sheets, the whole being invaded by granite from below. Scale about 1 : 100,000.

AA. The sedimentary series, with associated basic rocks.

BB. Zone of contact with the granite, in which all the types of rock, including the granite, become most profoundly modified. Some bands of quartzite, however, may remain almost intact, as shown by Barrois; some extensive flakes of metamorphosed argillaceous strata may also be preserved, as shown, for example, by Duparc and Mrazec on Mont Blanc.

CC. Zone where the granite, converted into gneiss, predominates; blocks and "eyes" of amphibolite are numerous, together with scattered micaceous masses, mostly drawn out into films.

D. Zone of the pure granite, showing, perhaps, some gneissic structure due to flow.

XZ. Line of the present surface, showing how the successive zones are revealed by denudation, with a possible appearance of unconformity on the right.

* Compare remarks on plutonic absorption, "Geology of Slieve Gallion," Sci. Trans. R. Dublin Soc., vol. vi., p. 240. The matter has now been strikingly dealt with by Prof. B. K. Emerson; "Differences in Batholitic Granites according to depth of Erosion," American Geologist, vol. xxiii. (1899), p. 105.

Too often, the contact-phenomena on a broad scale have been removed by denudation from the surface of our granite domes, and we encounter them only in horizontal section along the flanks of the igneous mass. Such observations can give us only a limited conception of the amount of metamorphism effected by the whole surface of the "batholite," and of the actual destruction wrought by it during the slow ascent of its material. After a time, its lateral boundaries may become fairly established, while the roof of schistose or stratified material may be continually collapsing. This upper region will be that of greatest weakness, of most continuous attack; and the evidence of interpenetration and absorption may be sought there with the best success.

During the field-work in the areas described, I have had the advantage of the company of Mr. J. A. Cunningham, A.R.C.Sc.I., both at Fir Mountain and in the county of Donegal, and of Mr. J. St. John Phillips, A.R.I.B.A., in the region around Pomeroy. I have also to thank Mr. H. J. Seymour, B.A., for help given in the examination of material collected by the Geological Survey of Ireland, and my Wife, for the drawings of microscopic sections that accompany the present paper.

DESCRIPTION OF PLATE XXVI.

MICROSCOPIC SECTIONS OF ROCKS OF TYRONE AND DONEGAL.

Figure

1. Junction of intrusive granite and diorite, Creggancorroe, Co. Tyrone, showing simulation of structures found in the more ancient gneisses. × 23. (Page 439.)

2. Intrusive granite near Craignayarrow, Co. Tyrone, showing patches of biotite formed from partly destroyed inclusions of gneiss and schist. × 23. (Page 443.)

3. Pure gneiss, with delicate bands of blackened biotite, south shore of Lough Derg, Co. Donegal. (See Pl. XXVII., fig. 1.) × 23. (Page 455.)

4. Band of biotite and garnet in coarse granite of Mountain Lodge Quarry, Co. Donegal, arising from partial absorption of the adjacent garnet-amphibolite. (See Pl. XXVII., fig. 3.) × 25. (Page 457.)

5. Junction of gneiss and amphibolite at Carn, Co. Donegal, showing foliated layers of biotite, with sphene, formed along the surface of contact. (See Pl. XXVII., fig. 6.) × 15. (Page 453.)

6. Garnet-pyroxene-amphibolite (hornblende-eclogite), typical example from the great "eye," Mountain Lodge Quarry. (See Pl. XXVII., fig. 3.) × 27. (Page 457.)

DESCRIPTION OF PLATE XXVII.

Figure

1. Large "eye" of amphibolite included in pale gneiss, which has flowed round it. South shore of Lough Derg, Co. Donegal. (Photographed by Mr. J. A. Cunningham.) (Page 455.)

2. Upper part of "eye" of amphibolite, overlain by pale gneiss on left. Both rocks are traversed by later veins of coarse granite. (The light patches on the right are due to lichens.) Townland of Shannagh, S.E. of Laghy, Co. Donegal. (Photographed by the author.) (Page 459.)

3. Quarry opposite Mountain Lodge, west of Pettigo, Co. Donegal. A. Amphibolite; Gn. Gneiss, wrapping round an "eye" of amphibolite in front on the right, and passing over a second mass of amphibolite at the back; P. Coarse granite, forming veins in the amphibolite and in the gneiss. (Photographed by the author.) (Page 457.)

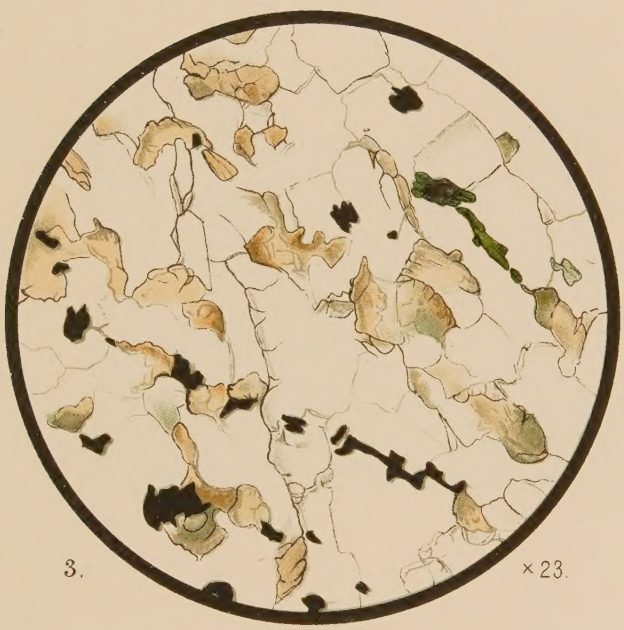
4. Biotite-Gneiss of Evishbrack, Co. Tyrone, with strongly differentiated layers, which may or may not be due to intrusion of granite into schist. $\frac{2}{3}$ nat. size. (Page 447.)

5. Vein of pale gneiss cutting amphibolite, south shore of Lough Derg, Co. Donegal. $\frac{6}{7}$ nat. size. (Page 456.)

6. Veins of gneiss and coarse granite in amphibolite, producing a rock with highly differentiated layers. Carn, N. of Pettigo, Co. Donegal. $\frac{3}{4}$ nat. size. (Page 453.)

1. × 23.

2. × 23.



3. × 23.

4. × 25.

5. × 15.

6. × 27.

B. Cole, del. McFarlane & Erskine, Lith. Edin.

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